Evolvable Space Systems

For Long-Life and Inherent Survivability

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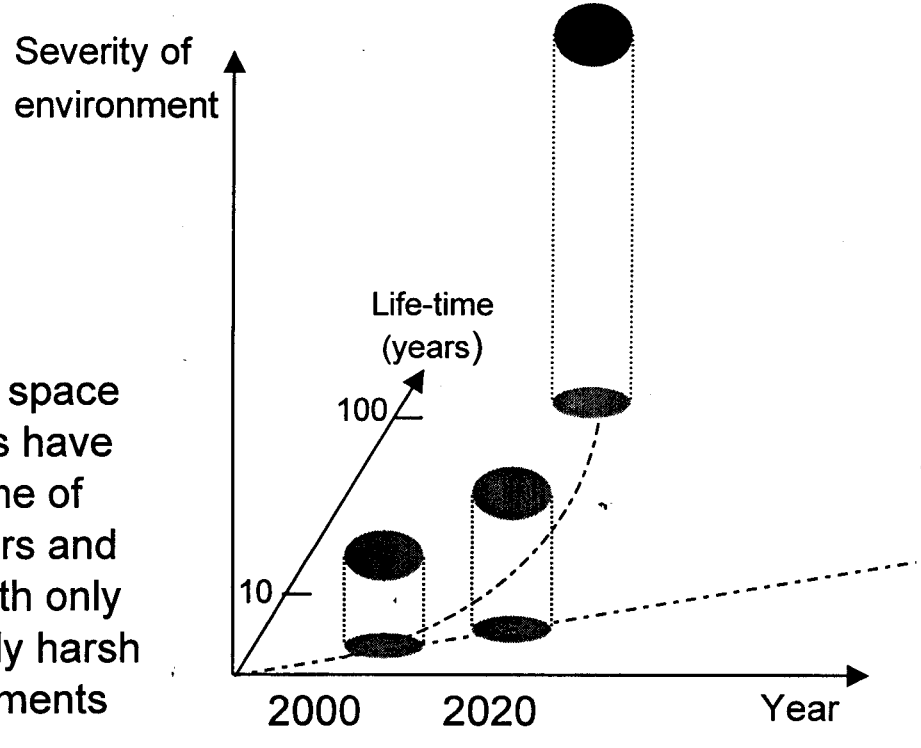
Biomorphic Explorers Workshop

August 19, 1998

Outline

- The need for a new paradigm
- Evolvability to increase survivability
- Goal: long life purposeful survivability
- Concept
- Inspiration and innovation
- How would this technology revolutionize NASA Missions
- Technical Challenges
- Technology Goals

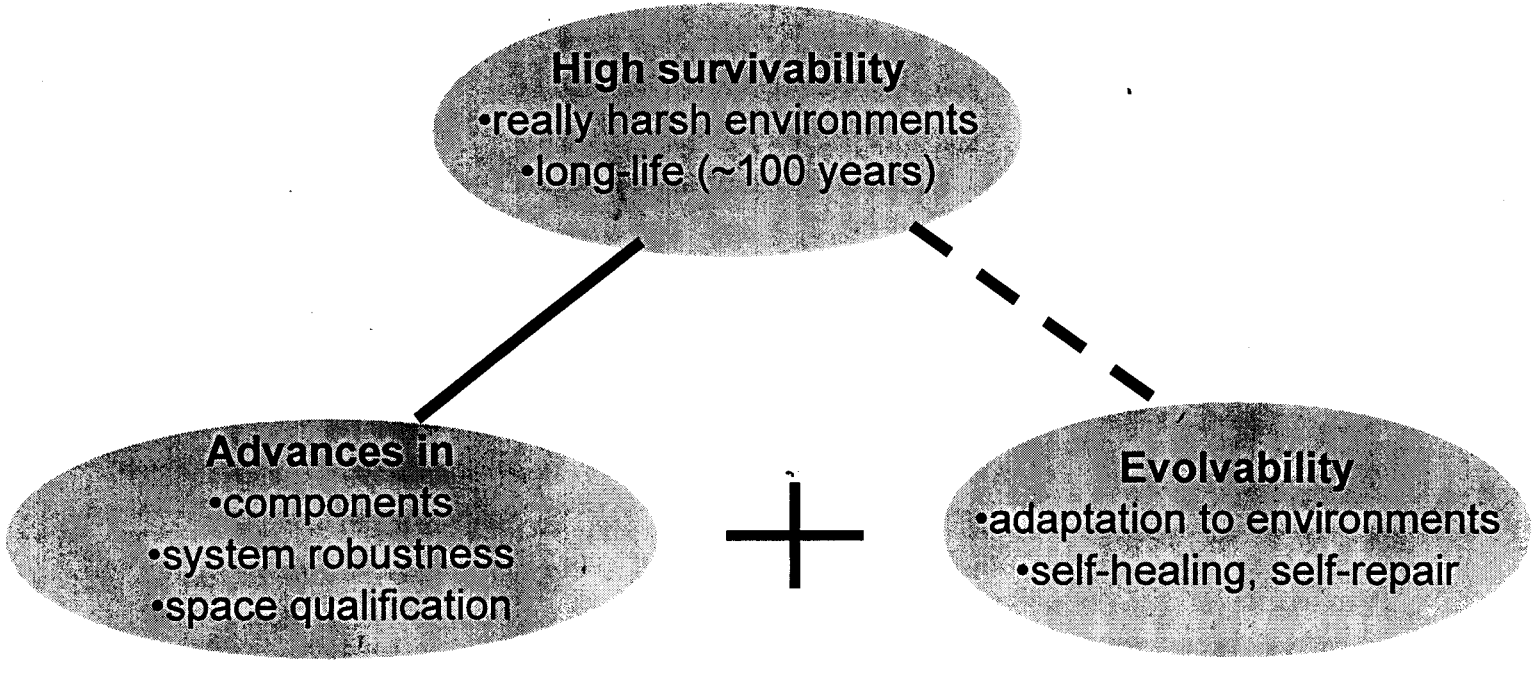
The need for a new paradigm



Current space systems have a life time of few years and cope with only modestly harsh environments

Current rate of increasing life-time and survivability in new environments may be not sufficient: a novel approach is needed to speed-up

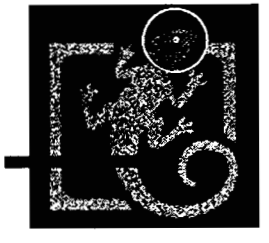
Add evolvability to increase survivability



Long life purposeful survivability

- *Purposeful* Survivability (100+ years)

- Change of focus
  - robust design from robust components



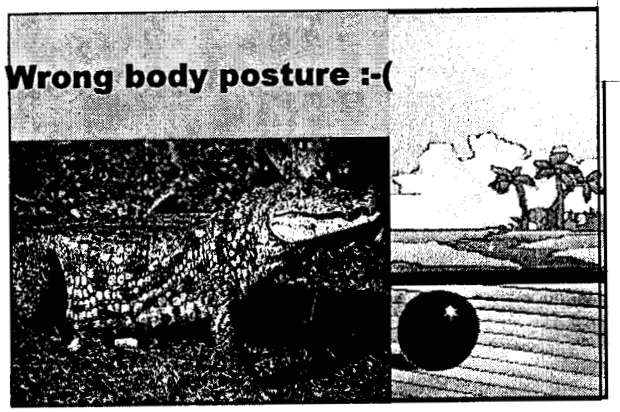
Chameleonic Space Systems

- Self-healing

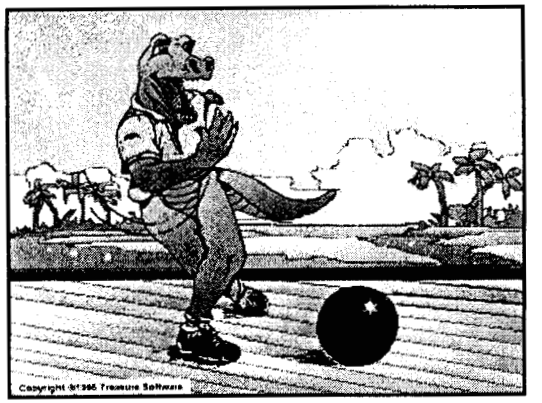
  - evolutionary robust design from flexible resources
    - repair
    - reallocation
    - reutilization

- Fleet, Swarm, Armada
- Some do not adapt, their resources unharmed resources are reused by survivors

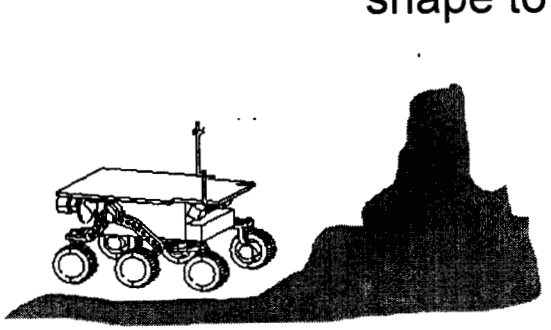
In-Situ Adaptation/Reconfiguration for the task

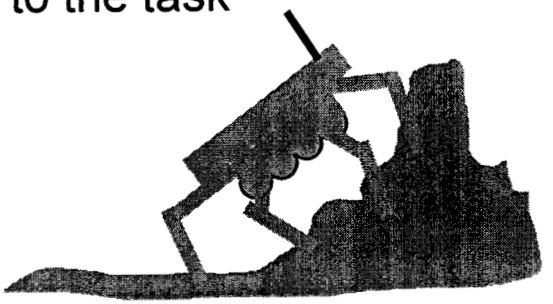


Task requires different body shape



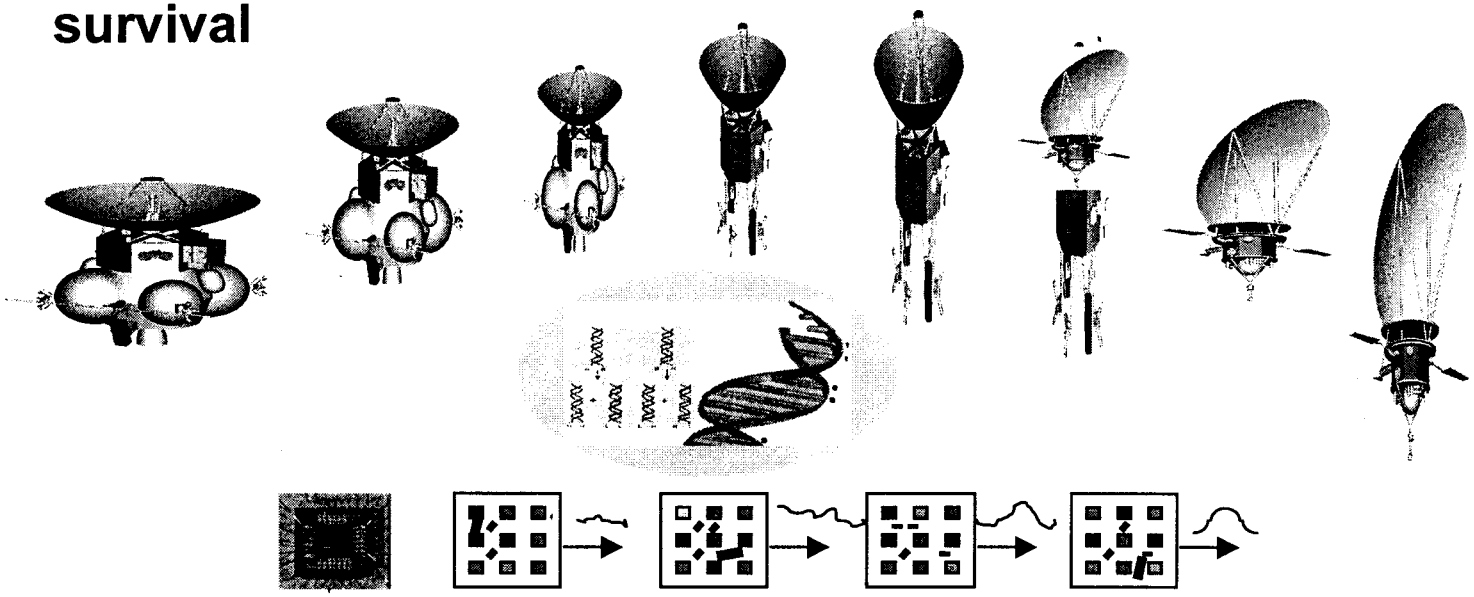
In-situ reconfiguration of body shape to adapt to the task





Evolvable Space Systems

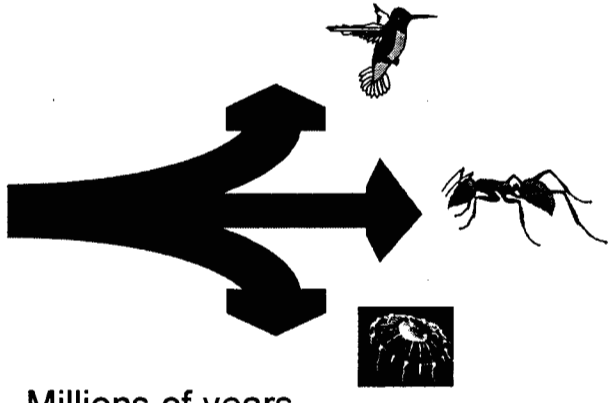
- Apply evolutionary algorithms to adaptively self-reconfigure space systems for long-life purposeful survival



- Evolution of Space Systems would include autonomous changes/reconfiguration of both software and hardware including sensors, avionics, structure...

Inspiration and innovation

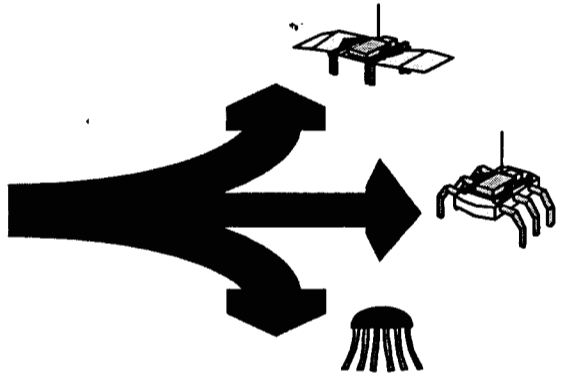
Evolution in nature has lead to species highly adapted to their environment - *adaptation ensured survival.*



Millions of years

The most fitted individuals survive becoming parents; children inherit parents characteristics, with some variations, may perform better, increasing the level of adaptation

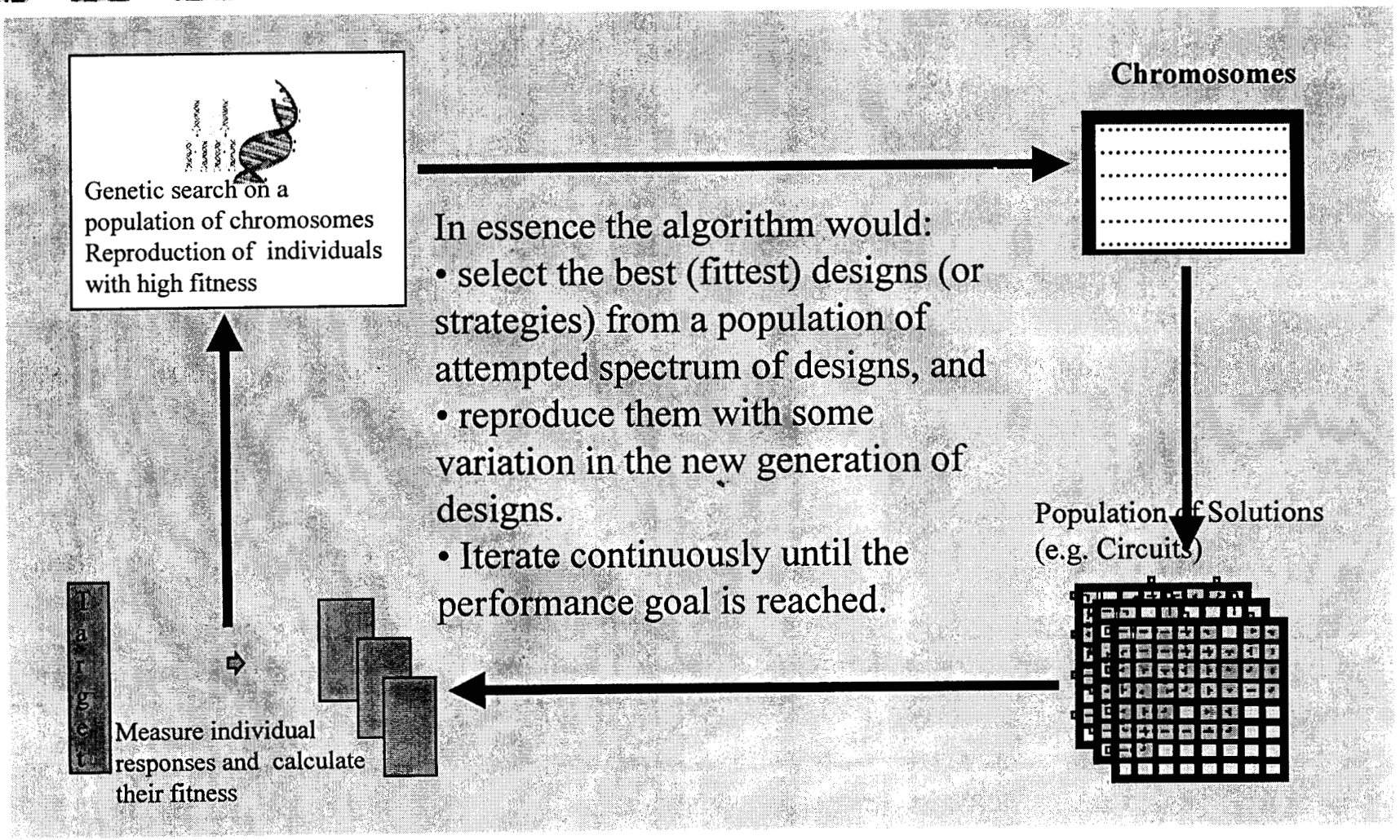
The same evolutionary principles can be applied to machines



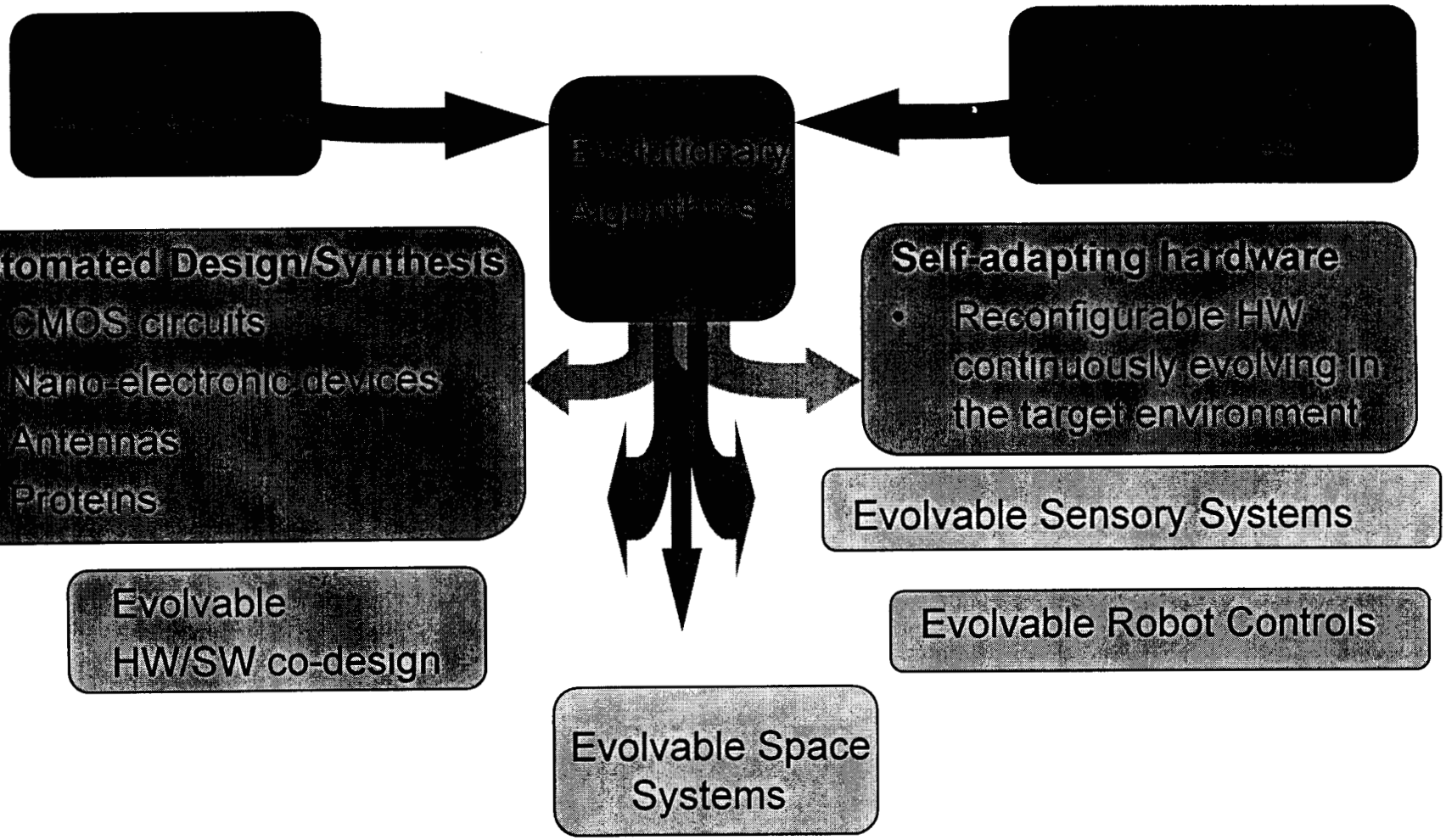
Potential designs and implementations compete; the best ones are slightly modified to search for even more suitable solutions

Accelerated evolution, ~ seconds for electronics

Evolutionary Algorithms



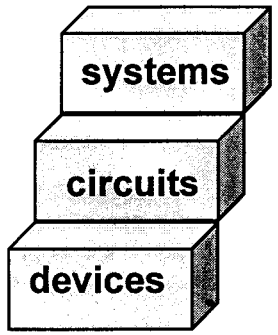
Evolware


Automated Design/Synthesis
CMOS circuits
Nano-electronic devices
Antennas
Proteins
Self-adapting hardware
Reconfigurable HW continuously evolving in the target environment
Evolvable Sensory Systems
Evolvable Robot Controls
Evolvable HW/SW co-design
Evolvable Space Systems

Evolution = Optimization

Artificial evolution is an optimization process. The optimization can be made for one or more characteristics simultaneously - e.g. function, cost, power, survivability, size

Optimization at design phase
- before mission -



Optimization during mission:
(optimal) adaptation to new situations, changes in requirements

Example:
- Evolve very small components
- Evolve multi-functional/reconfigurable components
- Evolve robust/fault-tolerant/self-healing components
- Evolve optimal designs at system level

Example
- Evolve new functions, unforeseen at launch
- Evolve for in-situ adaptation
- Evolve to self-heal

"Genetically Engineered" Nanoelectronic Devices

Gerhard Klimeck(385), Adrian Stoica (344)

Objective:

- Automated device synthesis and analysis using genetic algorithms.

Justification:

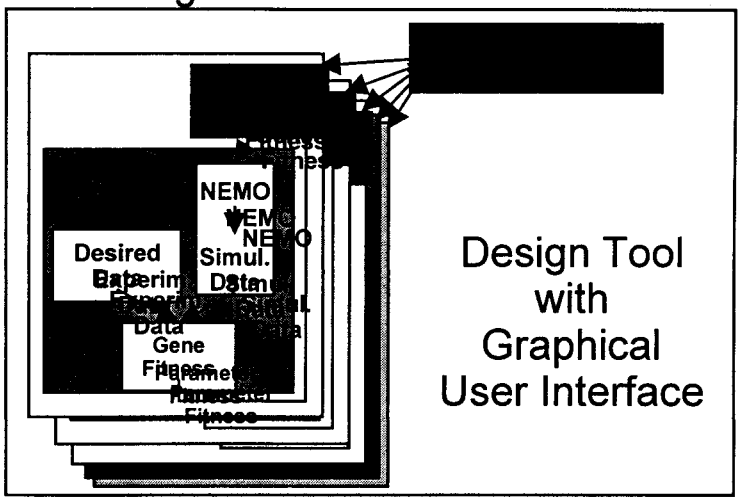
- Empirical Design (usual process) is sub-optimal. Complete design space search is unfeasible.
  => Develop automated design tools.

Impact:

- Rapid nanotechnology device synthesis and development.
- Generation of novel devices.

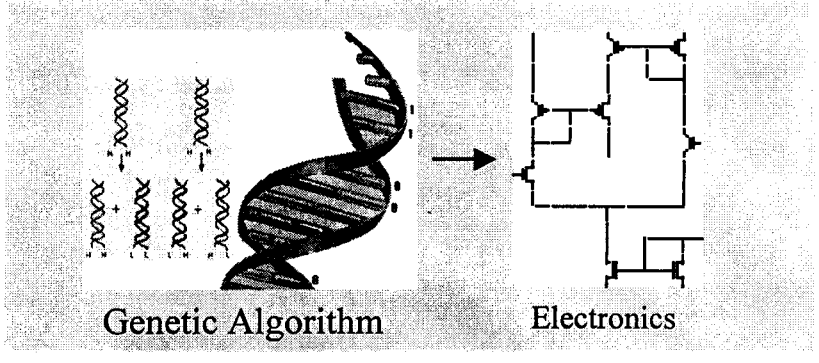
Approach:

- Augment recently developed advanced NanoElectronic MOdeling (NEMO) tool analyze individual structures in parallel.
- Augment parallel genetic algorithm package (PGApack) to optimize and select desired structures in NEMO.
- Develop graphical user interface to enable access to set of evolutionary quantum device design models.



Evolvable Electronic Circuits

Objective: Develop microelectronics chips capable of self-reconfiguration for adaptation to the environment

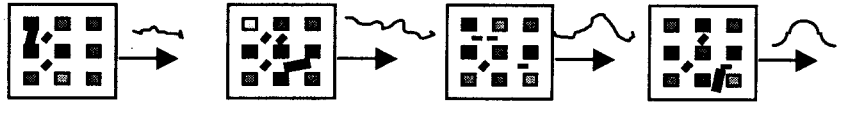


Approach:

- **Use reconfigurable cells**
- **Achieve self-organization by reassigning cell function & conncetions between cells**
- **Use powerful parallel seraches (e.g. genetic algorithms) directly in hardware, to evolve chip architecture**

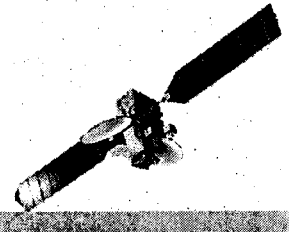
Payoff: Achieve high autonomy on-board spacecraft

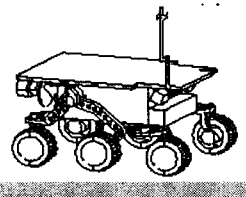
- **Maintain functionality under changes in operating conditions**
- **Provide new functions, not anticipated on ground**

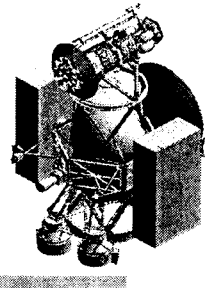


How Evolvable Space Systems would Revolutionize NASA Missions

- Long life, survivable, self-healing space systems
  - would allow long duration/far out missions
  - would harness required power and other resources from environment
- Would enable *evolvable missions* capturing science/exploration opportunities in real time
- Space explorer
  - would produce knowledge from acquired data
  - would use the knowledge to mission refocus/replanning
  - would be able to create new functions, unforeseen before launch
  - would be able to learn on-the-fly to best deal with changing conditions







Evolvable system technology:
adaptive platform for space systems in a large variety of missions

Technical Challenges

- Efficient representations, architectures, algorithms
  - Identify *DNA-equivalent* for a space system for it to become reconfigurable, evolvable, self-healing, capable of reconstructing after damage..
  - How to empower the system to *direct and execute* the evolutionary process
- Revolutionary advances in materials, components, and structures for inherent evolvability
- Breakthrough in validation techniques
  - Define *fitness functions* for evolvability

Technology Goals

10 years..

Evolvable Sensory Systems for Space Explorers

- Evolution of electronic circuits directly on-chip, performing a flight-relevant function (e.g. data compression)
- Intelligent adaptation of a science instrument
- Intelligent sequencing of instruments, adapt individual instruments
- Adaptive/Intelligent space sensory systems

15-20 years..

Evolvable Space Systems

- Adaptation of materials, structural/mechanical components, sub-assemblies
- Self-healing, automatic mission planning from high-level mission goals
- Long life, inherently survivable space systems